



U.S. Department of Energy
Energy Efficiency and Renewable Energy

DATA CENTER ENERGY EFFICIENCY TRAINING

Commissioning



<Presenter>



Data Center Commissioning Overview

- Roles and Responsibilities
- Cx Timeline
- Prefunctional Testing
- Functional Testing
- Trend Reviews
- Other Issues



Commissioning

- Level of commissioning
 - No “right” answer – it depends on amount owner is willing to spend vs. perceived and real benefit of a functioning system
 - Typically follows 80-20 rule: 80% of benefit achieved with 20% of effort, and to eliminate the last 20% of problems requires 80% more effort
 - Make the level appropriate for the building type and complexity of systems
 - Non-critical: Small retail and office
 - More critical: Large, complex buildings
 - Most critical: Data centers, central plants, labs



Current Commissioning Practice

- Includes:
 - Submittal review
 - Post construction walk-through
- Typically no testing beyond T24
 - Title 24 2005 requires some performance verification tests



Comprehensive Commissioning

- Comprehensive Cx:
 - 3rd party peer review of design and sequences
 - Detailed submittal review
 - Detailed programming review including simulations
 - Prepare pre-functional and functional test forms
 - Pre-functional test verification
 - Perform functional tests
 - All main systems
 - Subset of repetitive systems (e.g. VAV boxes)
 - Post-construction trend review
 - Post-occupancy trend review
 - Pre-warranty trend review
 - Fully documented all steps and submit Cx report



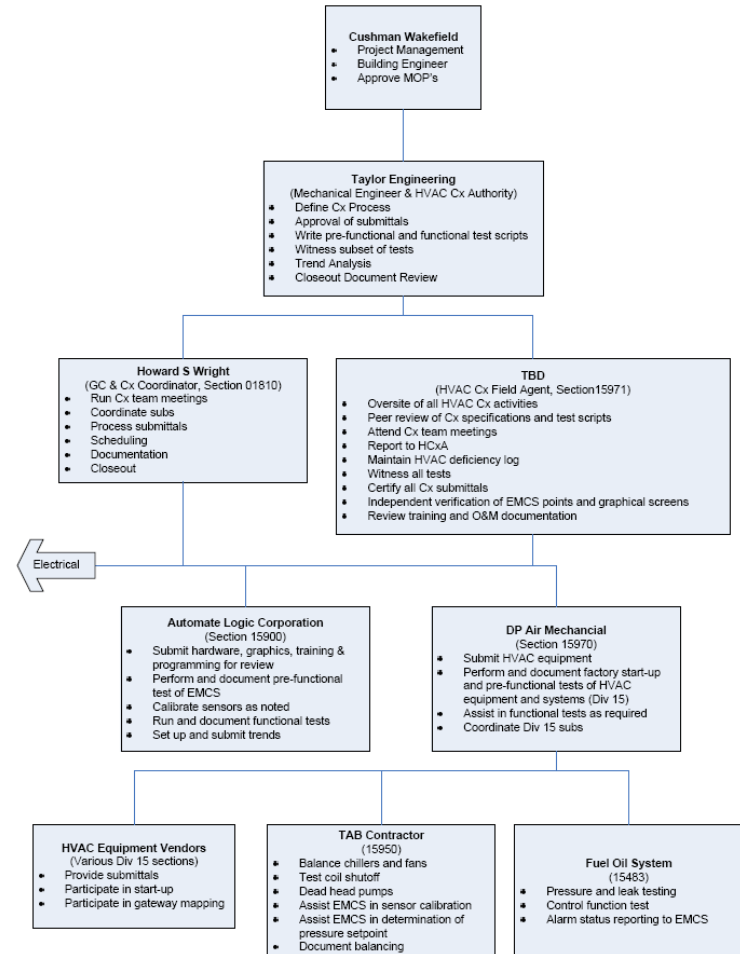
Who Does Commissioning

- Contractor
 - Current practice
 - Largely ineffective due to competitive pressures, lack of oversight
- Design engineer
 - Most familiar with design, but often not sufficiently experienced with controls
 - Cx not included in standard fees
- 3rd Party
 - No conflict of interest, but most expensive and can be disruptive
- Combination of above
 - Split work among various parties to minimize cost, take advantage of expertise
- Cx Plan must be clearly detailed in spec's!



Roles and Responsibilities

Specification Section	Owner/CM (Cushman Wakefield)	Engineer (Taylor, CxA)	HCxFA 15971	GC (HSWCC, CxC) 01810	HVAC (DP Air) Div 15	EMCS (ALC) 15900	TAB 15975	Vendors
	Approve	Create	Review		Review	Review	Review	Review
01810, 15050 & 15900	Review and Enforce	Specify and Approve		Review	Provide	Provide	Provide	Provide
01810	Attend as Required	Chair		Manage and Document	Attend All	Attend All	Attend as Required	Attend as Required
01810	Review and Enforce	Specify and Approve	Review	Create & Maintain	Support	Support	Support	Support
01810	Attend as Required	Attend as Required	Attend All	Manage and Document	Attend All	Attend All	Attend as Required	Attend as Required
01810	Review, Approve and Enforce	Support	Review	Create & Maintain	Support	Support	Support	Support
01810	Review and Enforce	Specify and Approve	Create & Maintain	Support	Execute	Execute	Support	Support
Div 15 Sections	Review and Enforce	Specify and Approve	Review	Review	Execute & Submit	Execute & Submit	Support	Support
Div 15 Sections	Review and Enforce	Approve	Witness & Certify	Support	Execute & Submit	Execute & Submit	Support	Specify and Support
15050	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support	Execute & Submit		
15950	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support	Execute & Submit	Support	Support
01810	Review and Enforce	Specify and witness	Witness & Certify	Support	Support	Execute & Submit	Support	Support
01810	Review and Enforce	Specify and Approve	Witness & Certify	Support		Execute & Submit		
15971	Review and Enforce	Specify and Approve	Execute and Submit	Support	Execute & Submit	Execute & Submit		
15900	Review and Enforce	Specify and Approve	Review & Certify	Support	Execute & Submit	Execute & Submit		Support
15050	Review and Enforce	Specify and Approve	Review & Certify	Support	Provide	Execute & Submit	Provide	Support
15050 & 15900	Review and Enforce	Specify and Approve	Review & Certify	Support	Execute & Submit	Execute & Submit		Support
15050 & 15900	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support	Support	Support	Support
15050 & 15900	Approve	Recommend	Witness & Certify	Support				
01810	Review	Specify and Approve		Execute & Submit	Support	Support	Support	Support





Timeline (from EMCS Specification)

1. Submit Submittal Package 1 (Hardware and Shop Drawings) and receive approval.
2. Initiate installation of EMCS hardware, devices and wiring.
3. Develop point database and application software.
4. Simulate sequencing and debug programming off-line to the extent practical.
5. Submit Submittal Package 2 (Programming and Graphics) and receive approval.
6. Complete installation of EMCS hardware, devices and wiring.
7. Install point database and application software in field panels.
8. Submit Submittal Package 3 (Functional Testing) and receive approval.
9. Perform EMCS Pre-functional Tests (start up, calibration and tuning) and submit Pre-functional Tests for approval.
10. Field test application programs prior to functional testing.
11. Receive EMCS Pre-functional Test Report approval and approval to schedule Functional Tests.
12. Assist TAB contractor in TAB tests and determining setpoints as specified in Section 15950.
13. Perform and record functional tests and submit Functional Test Report for approval.
14. Submit Package 4 (Training Materials) and receive approval.
15. Receive EMCS Functional Test Report approval and approval to schedule Demonstration Tests.



Timeline, continued

16. Perform Demonstration Tests to Commissioning Coordinator and Owner's Representatives and submit Demonstration Test Report.
17. Receive acceptance of Demonstration Tests.
18. Train Owner personnel on EMCS operation and maintenance.
19. Substantial Completion.
20. Prepare and initiate commissioning Trend Logs.
21. Submit Submittal Package 5 (Trend Logs) in format specified for review and approval.
22. Receive approval of successful Trend Log tests, or retest as required.
23. Complete all items in Completion Requirements
24. Provide administration level password access to the Owner.
25. Final Acceptance.
26. Begin Warranty Period.
27. Prepare and initiate post-occupancy Trend Logs.
28. Two months prior to end of Warranty Period, submit Submittal Package 6 (Trend Logs) in format specified for review and approval.
29. Receive approval of successful Trend Log tests, or retest as required.
30. Revise and submit record documents and O&M Manuals.
31. Update all software as specified.
32. End of Warranty Period.

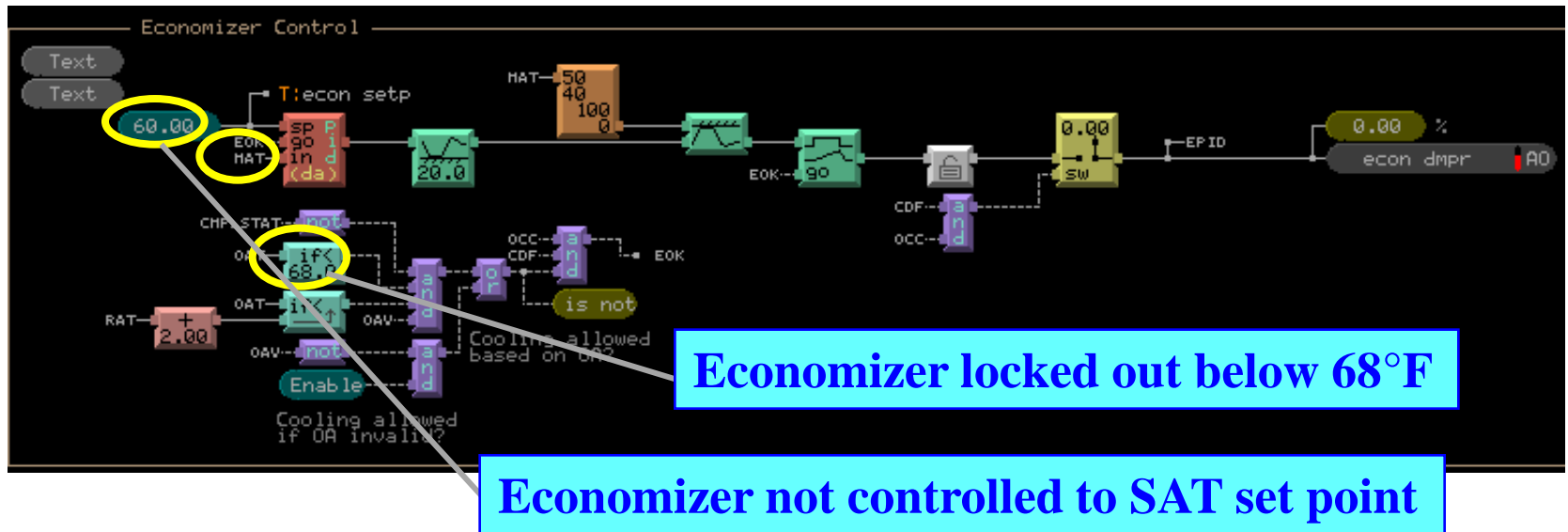


Programming Review

- Not intended to debug programming
- Just to make sure specified sequences were actually followed
 - Most contractors will use programming developed from previous jobs
 - OK provided spec'd functionality is maintained



Programming Review Example



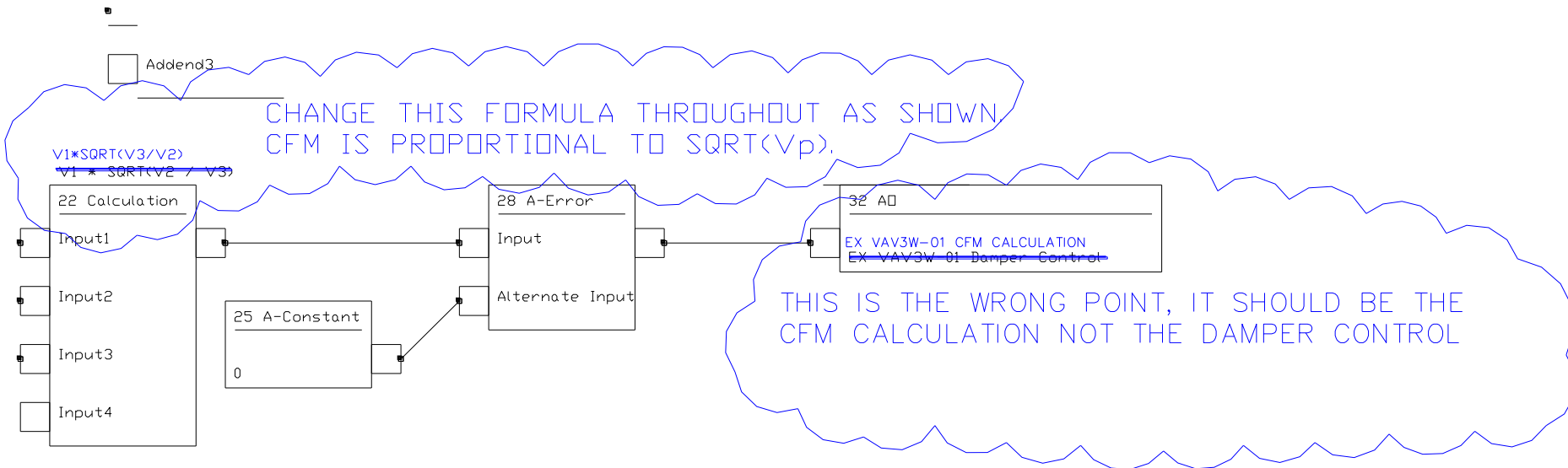


Programming Review Example

- Economizer is controlling to mixed-air temperature (MAT) not supply-air temperature (SAT)
- Economizer is controlled to a fixed 60F. Specs call for the economizer to be controlled to reset SAT setpoint using same SAT PID loop controlling mechanical cooling
- Economizer is disabled when $OAT > 68F$. Specs say it is disabled when outdoor air temperature exceeds the return air temperature



Example Programming Review





Pre-functional tests

- Augments and documents manufacturer's start up procedures for equipment
- Includes some system testing like
 - Pipe pressure testing
 - Duct leakage testing
 - Valve leakage tests
- May include factory witness testing (e.g. chillers)



Control system pre-functional tests

- **General**
 - Inspect the installation of all devices.
 - Verify integrity/safety of all electrical connections.
 - Verify that all sensor locations are as indicated on drawings
- **Digital Outputs**
 - Verify DOs operate properly and that the normal positions are correct.
- **Digital Inputs**
 - Adjust setpoints, where applicable.
- **Analog Outputs**
 - Verify start and span are correct and control action is correct.
- **Analog Input Calibration**
 - Calibrated as specified on the points list
 - Inaccurate sensors must be replaced if calibration is not possible.



Calibration Log

ID No.	Cal.Temp	Reading	Offset
AHU-1 SAT	53.2	53.2	0
Ahu-2 SAT	53.7	51.7	2
Ahu-3 SAT	52.6	51.4	1.2
Ahu-4 SAT	53.1	52.4	0.7
Ahu-5 SAT	58.6	59.9	-1.3
BLDG HW Supply	150	150.1	-0.1
BLDG HW Return	150	149.7	0.3
Primary HW Supply	150	150	0
BLDG CHW Supply	80	79.7	0.3
BLDG CHW Return	80	79.6	0.4
Primary CHW Supply	80	79.9	0.1



Pre-functional tests, continued

- Alarms and Interlocks:
 - Check each alarm separately by including an appropriate signal at a value that will trip the alarm
 - Verify internal and external response to alarm (email, page)
- Gateways
 - Verify operation and map across points
- Loop Tuning
 - Achieve specified stability
- Operator Interfaces
 - Verify that all elements on the graphics, functional and are bound to physical devices
 - Verify hyperlinks
- Trending/Network Traffic Test
- TAB tests
 - Setpoint Determination, e.g. DP and minimum outdoor air damper position



Functional Tests

- Scope
 - Test every sequence
 - Test every unique subsystem and a subset of multiple subsystems (e.g. VAV boxes)
- Format
 - Test form to include setup, steps, expected response, and actual response
- Who does prepares and performs tests?
 - May be contractor, engineer, or 3rd party Cx agent
 - We often have the engineer prepare and witness them and the contractor performs them





Functional Tests

I. Chilled Water Pumping System

The following is from the specifications for bypass valve, minimum flow control:

<u>Chiller Stage</u>	<u>Chillers operating</u>	<u>Minimum Flow</u>
1	1 small, 0 big	250
2	2 small, 0 big	480
3	1 small, 1 big	595
4	2 small, 1 big	825
5	1 small, 2 big	940
6	2 small, 2 big	1,170
7	3 small, 2 big	1,400
8	4 small, 2 big	1,605

The following is from the specifications for pump staging:

CHW Pumps Operating	Nominal flow	Stage up to this stage if flow exceeds this for 5 minutes	Stage down to lower stage if flow is below this for 5 minutes*
1	650 gpm	--	--
2	1,300 gpm	650 gpm	490 gpm
3	1,950 gpm	1,300 gpm	975 gpm
4	2,600 gpm	1,950 gpm	1,450 gpm

<u>Unit(s) Tested:</u>		<u>Tested by: Mark P & Gary K.</u>		
<u>Action</u>	<u>Expected Response</u>	<u>Observed Response</u>		<u>Date/Time</u>
At the chillers and the EMCS system, read and record the flowrates from each of the operating chillers. Read and record the EMCS calculated plant flowrate.	The plant flow rate should equal the sum of the flow meters on all of the operating chillers	Flowrates (gpm) At Meter At EMCS		11/16/06 3:23pm
Chillers were locked on.	The EMCS flow rate should	CH-1: 245.1	245.5	
		CH-2: 274.0	274.5	
		CH-3: 124.6	124.6	
		CH-4: off	off	



Functional Tests

Unit(s) Tested:		Tested by: Mark P & Garv K.	
Action	Expected Response	Observed Response	Date/Time
	match the flowrate on the faceplate of the flow meters	CH-5: off off CH-6: off off Plant: ----N/A-----	
For each pump, read and record the minimum speed setpoint in the drive 20% ---100% BAS 20Hz----60Hz VFD	Either the VSD minimum or the EMCS minimum should be 0. The other should be set to 10% (6HZ)	Minimum setting VSD EMCS P-1: 20Hz 20% P-2: 20Hz 20% P-3: 20Hz 20% P-4: 20Hz 20%	11/16/06 3:30pm
Read and record the following data: <ul style="list-style-type: none"> Total plant flowrate (EMCS, gpm) Current DP setpoint (EMCS, psi) Current DP at the sensors in the distribution loop (EMCS, psi) Which pumps are running Current pump speeds (both at the EMCS and on the VSD panel) <p>At the EMCS increase the DP setpoint by 10% to 15%.</p> <p>Wait 3 minutes.</p> <p>Read and record the following data:</p> <ul style="list-style-type: none"> Total plant flowrate (EMCS, gpm) Current DP setpoint (EMCS, psi) Current DP at the sensors in the distribution loop (EMCS, psi) 	DP sensor reading should be stable at DP sensor setpoint. The VSD should have sped up to get the DP sensor reading to the new setpoint. There should be no hunting of the VSD speed or actual loop pressure. The plant flow rate should not change appreciably. The number of pumps running should be as follows: <ul style="list-style-type: none"> 1 for flow between 0 and 490 gpm 1 or 2 for flow between 	As-is data Plant flowrate: 637.5 DP setpoint: 15# DP reading 1: 14.8 # DP reading 2: NA Pump Speeds/Status (0=OFF) VSD EMCS P-1: 49.9 83.5 P-2: 0 P-3: 0 P-4: 0 Post setpoint change data Plant flowrate: 695.8 DP setpoint: 17.0 DP reading 1: 16.5 DP reading 2: NA Pump Speeds/Status (0=OFF)	



More Functional Tests

- Shut off devices and watch system response (e.g. start of backup pump)
- Check alarms and response
- Override setpoints and watch system response
- Push system to extremes (full cooling/heating)
- Power system down and check recovery
- Observe system as it operates





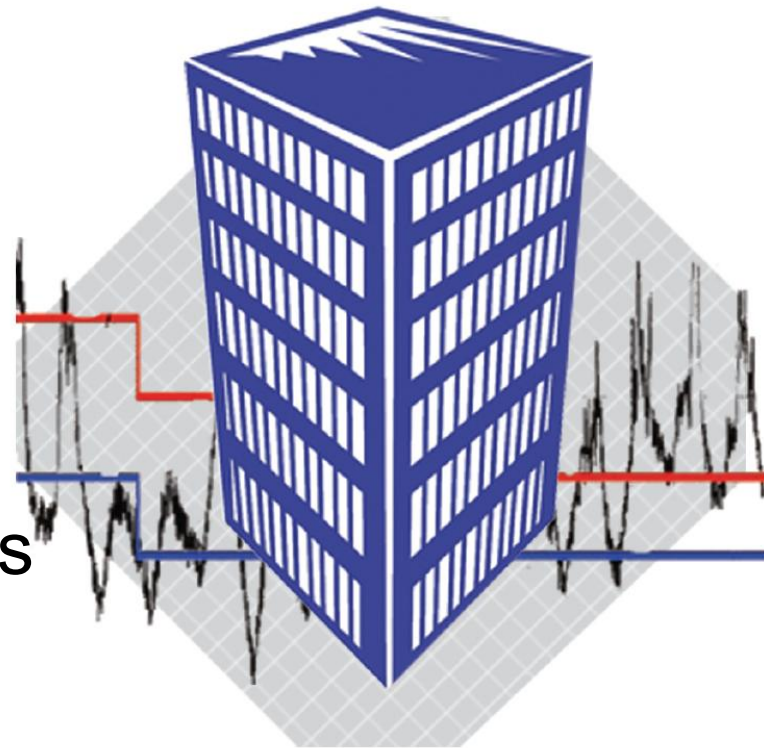
Trend Reviews

- Required even when detailed functional tests are performed
 - Functional tests mimic control sequences – they prove programming matches sequences but cannot identify bugs in sequences
- Less expensive than comprehensive functional testing with proper analysis tools
 - But trends do not generally show faults – they must be tested in the field since they may not occur during trend period
- Requires experienced eye – design engineer with controls experience who is very familiar with sequences and HVAC systems



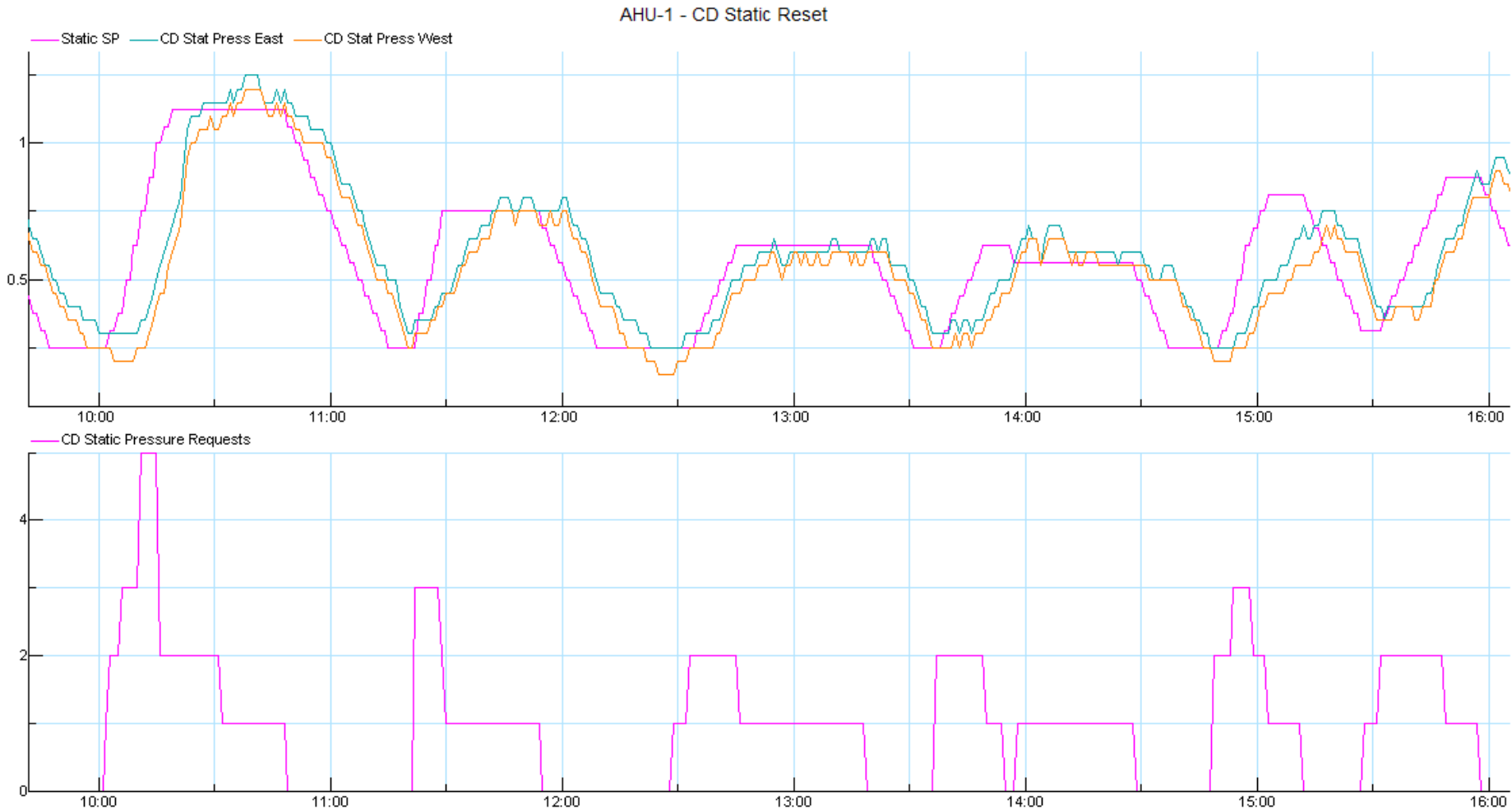
DDC Trend Reviews

1. Collect Trends using DDC system
2. Massage data
 - Software tool enables import, normalization, sorting, grouping and exporting of trends
3. Perform statistical analysis
4. Graph selected variables
5. Analyze results



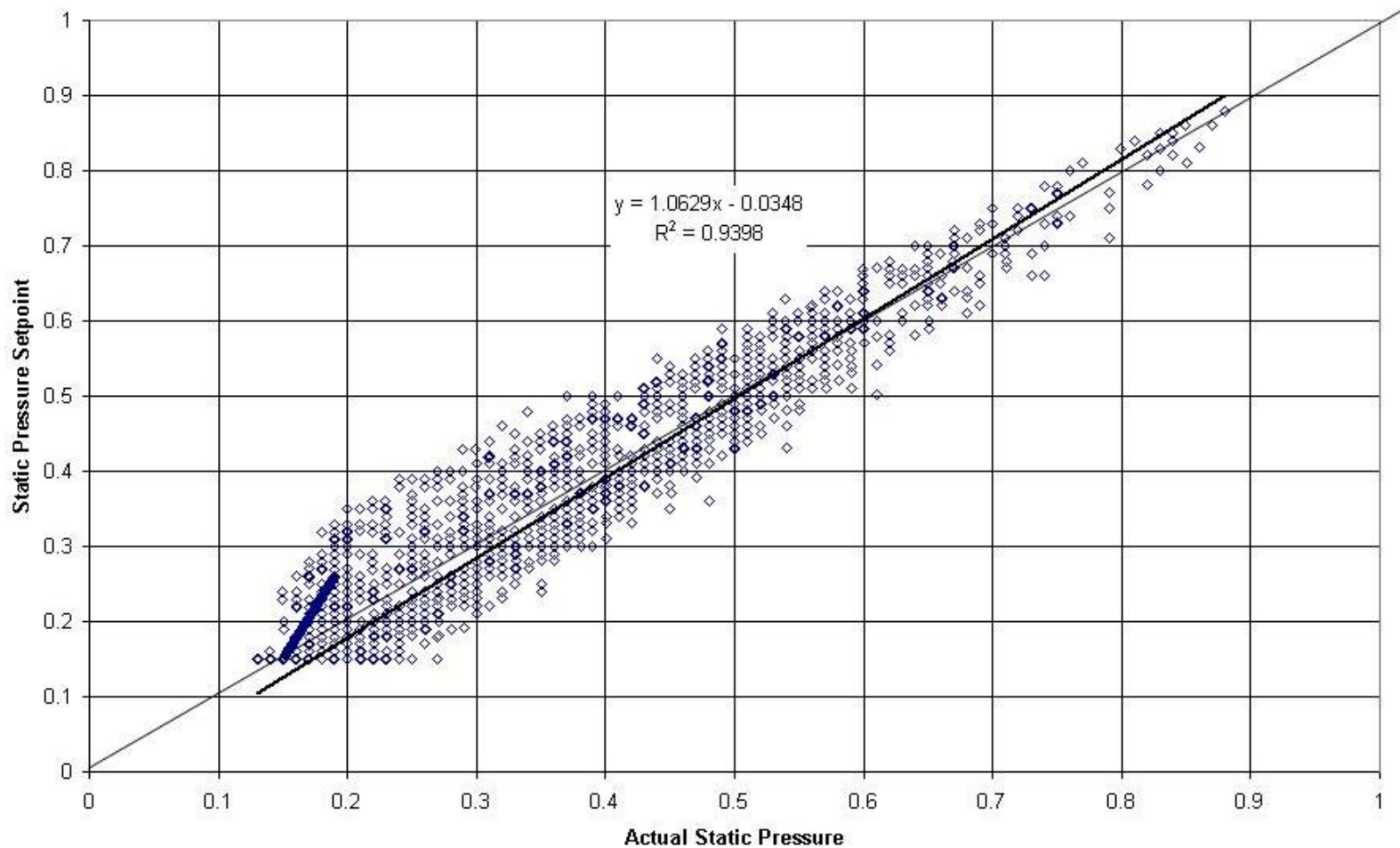


Time Series Static Pressure Reset





Scatter Plot Loop Tuning, Reset



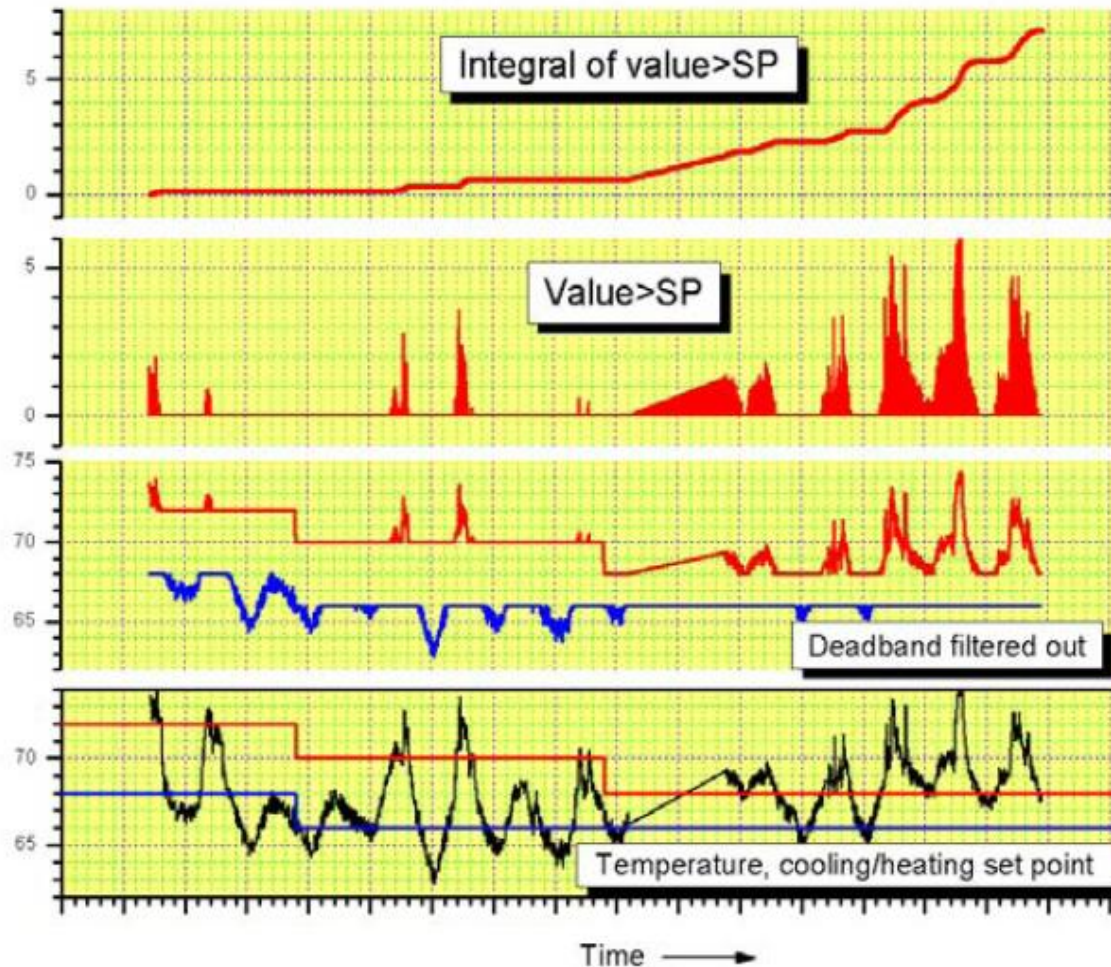


Statistics

Date	Minutes of Warmup	Average OAT	Minimum OAT	Minimum N	Minimum E	Minimum W	Minimum S	Maximum N	Maximum E	Maximum W	Maximum S	Day of Week
Occupied Hours												
12/12/2001	0	51	45	67	70	69	70	73	73	73	74	Wed
12/13/2001	0	49	44	67	70	69	70	70	73	71	73	Thurs
12/14/2001	0	50	44	66	70	68	69	69	73	72	74	Fri
12/17/2001	0	52	48	64	66	66	67	72	73	72	77	Mon
12/18/2001	0	50	43	65	68	67	68	72	73	72	74	Tues
12/19/2001	0	51	44	65	67	-	68	73	75	72	74	Wed
12/20/2001	0	48	46	66	69	68	68	72	74	72	75	Thurs
12/21/2001	0	44	44	64	67	67	67	66	69	68	71	Fri
12/26/2001	0	45	45	68	69	68	69	68	69	68	69	Wed
12/27/2001	0	49	45	69	70	69	70	73	72	71	75	Thurs
12/28/2001	0	49	47	68	68	69	69	73	73	71	75	Fri
12/31/2001	0	56	51	65	66	67	67	72	73	71	74	Mon
1/2/2002	0	52	50	65	66	67	67	71	73	73	72	Wed
Unoccupied Hours												
12/12/2001	0	49	47	68	71	70	70	71	71	71	72	Wed
12/13/2001	18	46	44	66	69	69	69	70	72	70	71	Thurs
12/14/2001	19	45	43	66	70	69	68	69	72	70	73	Fri
12/15/2001	0	46	41	64	67	67	67	66	70	72	72	Sat
12/16/2001	0	48	44	63	66	66	66	65	68	68	68	Sun
12/17/2001	18	48	45	63	66	66	66	71	71	70	72	Mon
12/18/2001	18	45	43	65	68	67	67	71	71	71	71	Tues
12/19/2001	0	46	44	65	68	67	67	72	72	70	71	Wed
12/20/2001	19	45	43	66	68	68	68	72	70	71	72	Thurs
12/21/2001	0	44	43	64	67	67	67	66	68	68	68	Fri
12/27/2001	16	49	45	68	69	68	69	70	70	70	71	Thurs
12/28/2001	18	48	46	67	68	69	69	71	71	70	72	Fri
12/29/2001	0	48	46	66	67	68	68	67	69	69	69	Sat
12/30/2001	0	51	49	65	66	67	67	66	67	68	68	Sun
12/31/2001	18	52	50	65	66	67	66	71	71	70	71	Mon
1/1/2002	0	52	50	65	67	67	67	67	68	69	69	Tues
1/2/2002	0	51	50	65	66	67	67	66	67	67	67	Wed



Combination of Statistics, Time Series





Pivot Table or Summation Query

CT1_SS	CT2_SS	Instances (5 min)	Avg. CH1 CWST	Avg. CH2 CWST	Set Point	Pct
FAST	FAST	197	68.2	66.2	VHIGH	7%
FAST	SLOW	16	65.2	64.9	VHIGH	1%
FAST	STOP	24	65.0	65.8	N/A	1%
SLOW	FAST	86	66.4	65.0	VHIGH	3%
SLOW	SLOW	4	65.2	65.5	VLOW	0%
SLOW	STOP	39	63.7	64.1	VLOW	1%
STOP	FAST	787	65.9	67.9	N/A	27%
STOP	SLOW	1798	62.8	66.7	VLOW	61%
STOP	STOP	1	60.2	64.8	VLOW	0%



Other Commissioning Issues

- One person on site must coordinate all Cx activities
- Hold regular weekly Cx meetings
- Use of load banks
- Detail recovery procedures for testing on live data centers
- Carefully coordinate electrical, mechanical and control testing to save time and costs



Best Practices for Commissioning

- Specify thorough commissioning for data centers
- Be specific on roles and responsibilities
- Have an experienced Cx Coordinator on the site
- Hold weekly Cx meetings with all trades represented
- Carefully coordinate electrical, mechanical and control system testing



Take Aways

- No “right” way to perform commissioning
- Comprehensive Cx involves many steps
- Various approaches—contractor, engineer, 3rd party, combo
- Commissioning plan must be in specifications
- Controls programming should be reviewed
- Prefunctional and functional tests verify system and component function
- Trend reviews while not as comprehensive can identify problems
- Coordination is important during commissioning